FUSING SCIENTISTS' AND STUDENTS' CONCEPTUAL CORRESPONDENCES TO IMPROVE TEACHING OF METAL COMPLEX ISOMERISM IN HIGHER EDUCATION-AN EDUCATIONAL RECONSTRUCTIVE PROCESS

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ABSTRACT

The study was conducted to explore Scientists' and Students' perspectives on metal complex isomerism. These correspondences formed a powerful grain for conceptual change in content-oriented instruction for 15 third year chemistry major students at the University of Education, Winneba-Ghana. The interpretive case study was used to explore students' responses on geometrical isomers of complexes. Based on the researchers` interpretation and the Model of Educational Reconstruction (MER), a clarification of geometrical isomerism in coordination chemistry content structure was developed. The generated conceptions from four (4) university-level textbooks and students, primarily informed this clarification process. These conceptions on metal-complex isomerism (geometrical) from scientists and students were brought into meaningful correspondences. All data were analysed by qualitative content analysis, addressing students` reasoning during a ten (10) week class sequence. The research afforded students access to use their constructed knowledge rather than being passive recipients of scientist-presented knowledge. The study discussed the relevance of geometrical isomerism in Higher Education (HE).

Keywords: Constructed knowledge, correspondences, Educational Reconstruction, geometrical, isomerism, metal complex.

INTRODUCTION AND THEORETICAL BACKGROUND

Isomerism is a phenomenon that arises when two or more structures have the same number and kinds of atoms with the same molecular weight (same empirical formula) but at the same time different physical and chemical properties. Isomerism can be divided into two principal types: Structural and Stereoisomerism. Each of these can further be sub-divided, as represented in Figure1.

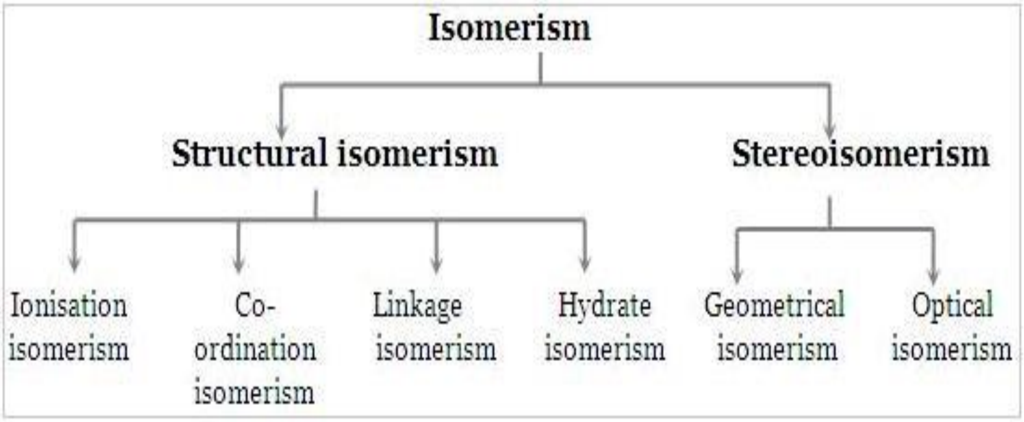

Figure 1: Tree chart of isomerism in complexes derived from Demitras, et. al. 1972

Out of these two principal types, stereoisomerism, is the more interesting and more important, as far as this study is concern. Stereoisomers differ from each other only in the intra-molecular orientation of the molecule in space. That is, the spatial arrangement of the atoms around a central atom.

In a study on a more elaborated level to identify representations of compounds, Schmidt (1992) asked students to identify isomers, from four (4) compounds given, as structural or condensed formulae. He found that students classified isomers on the basis of their functional groups but disregarded the possibility of constitutional isomerism. He concluded that students appreciate some key aspects of what stereoisomers are, but restrict their application of the idea to a class of organic compounds and not to inorganic metal complexes. The study therefore puts forward the fundamental postulates of Werner`s coordination theory: that ligands surrounding a central atom either in the solid state or in solution would be oriented in certain specific ways to form a regular geometric pattern. Thus, a group of six similar ligands would surround a central metal so as to yield a regular octahedral arrangement of which the (cis-trans) isomerism could be observed.

By this, observable learning theories suggest that representational competence can be fostered by explicitly engaging students in the creation of various representations and reflections on students` own meanings (Wirtz, Kaufmann, & Hawley, 2006). This concept of isomerism needs to be expanded beyond courses in organic chemistry to aspects of inorganic metal complexes.

Inorganic metal complex knowledge is of general significance, in that it may be applied in many different subject situations such as in biocoordination chemistry and toxicity in living systems, where metal ion is of great importance. For that matter, this study seeks to show the correspondences between scientific knowledge and students' conceptions about geometrical isomerism of metal complexes. Science concepts and principles should not be presented in the abstract form but in a reasonable context for learners. The study adopted the Model Educational Reconstruction (MER), because abstract/masked issues in the process of scientific knowledge of metal complex isomerism have to be restructured to make the science point of view understandable and meaningful to students. Hence, students' perspectives are systematically related to the scientific explanations on isomerism, so that both can fruitfully be made use of in the processes for instruction and learning. Educational reconstruction, according to Kattmann (1997), unavoidably influences the analysis of content structure. Thus, this study considered this reconstruction model for restructuring the content structure on geometrical isomerism based on scientists` and students` correspondences in Figure 2.

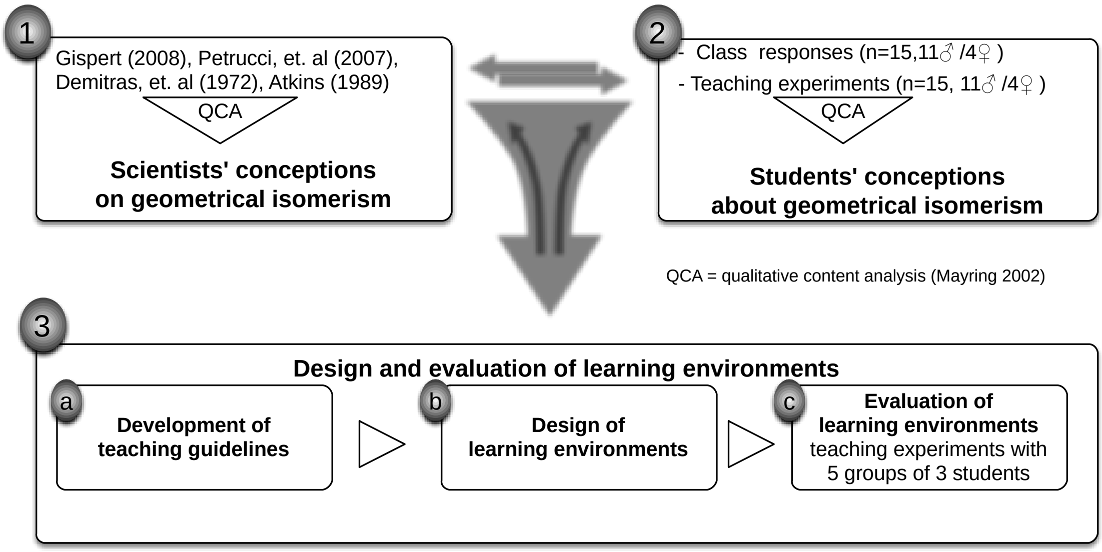

Figure 2: A Research design derived from the Model of Educational Reconstruction (Niebert & Gropengiesser, 2013)

From Figure 2, the MER is led by students' learning capabilities on the left hand side (2) and science content on the other hand (1) (Niebert & Gropengiesser, 2013). In order to let our students appreciate the MER design, and engage with it appropriately, we linked the design of the model (that is idea) to a laboratory double-pan balance to serve as a concrete picture of how the model works. The result of this comparison is represented in Figure 3.

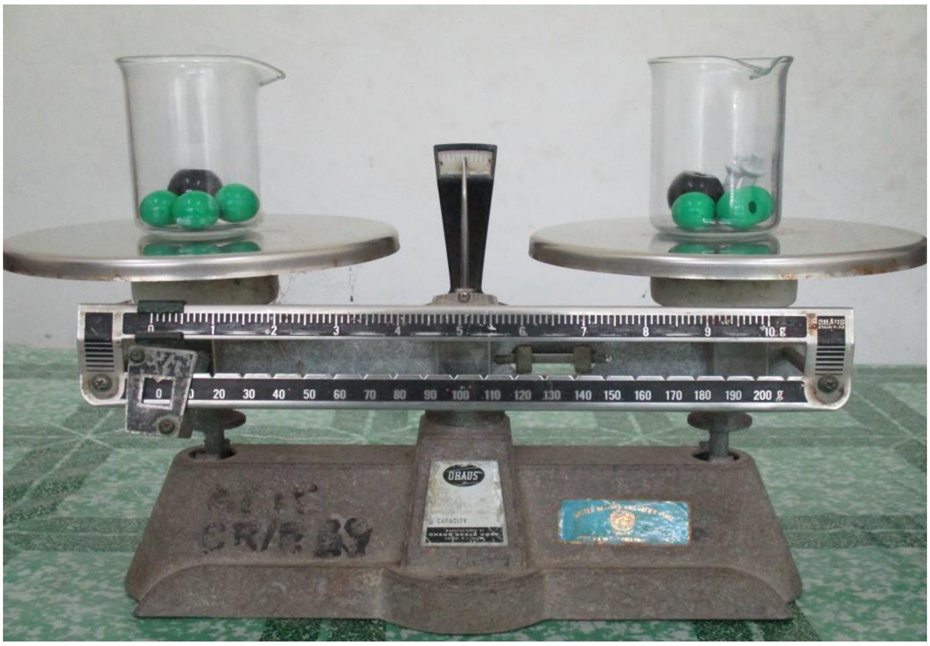

Figure 3: A laboratory double-pan balance as a representative idea of the MER.

In the representative model in Figure 3, students' ideas are conceptualized as items in one beaker and the scientists' ideas as items in another beaker, which are adjusted by adding on or taking away until a 'true' or `authentic balance` is achieved between the two perceptions-in this demonstration, items in the beakers. The MER has been used by some researchers to conduct studies on nomenclature and geometry of metal complexes (Sam, Niebert, Hanson, & Twumasi, 2015); climate change (Niebert & Gropengiesser, 2013); evolution (Zabel &

Gropengiesser, 2011); cell division (Riemeier & Gropengiesser, 2008); principles of vision (Gropengiesser, 1997) and to improve instructional practices and professional teacher development programmes (Duit, Gropengieser, Kattman, Komorek, & Parchman, 2012). These studies have demonstrated a successful content-oriented educational research through the MER.

In this study we show how the MER serves as a framework to balance scientists` and students` conceptual correspondences and leads to fruitful teaching. There is no evidence of studies on geometric isomerism of metal complexes within the West African region and Ghana in particular for which the concept of MER has been used. The main goal of our study was to adopt the well-known MER to improve teaching of isomerism of complex compounds in higher education in Ghana. The following research questions were addressed in the study:

a. What conceptions do students hold about geometric isomerism?
b. What teaching approach could be used to merge students' conceptions on isomerism, with that of scientists in order to bring a balance between the two conceptions and thus enhance the students' understanding?

METHODOLOGY

A qualitative, interpretive approach was employed in this research study (Merriam, 1998; Stake, 1995). The study sought to explore students` perceptions on geometric isomerism and incorporate into scientists` views. This kind of qualitative research provides rich description of experiences from students to generalize views about the nature of their prior knowledge on isomerism. The subjects for the study were fifteen (15) third year university chemistry major students (11 men and 4 women) from an intact class. Our study included data collection through multiple methods and from multiple sources (Merriam, 1998). We extracted scientists` conceptions on geometric isomerism from four (4) university-level textbooks (Gispert, 2008; Petrucci, Harwood, Herring, & Madura, 2007; Atkins, 1989, Demitras, Russ, Salmon, Weber, & Weiss, 1972). Students` were grouped and presented with four metal complexes of the formulae MA_4B_2 to identify cis- and trans-isomers, with explanations. Students` explanations about the cis-/trans isomerism were audiotaped in a ten (10) week class sequence for 120-minutes per week.

Transcripts from the students` groups, field notes and reflective pieces were then read independently in our research team and coded for emergent themes. The themes were manifestations from students` conceptions on isomerism. These themes and scientists' conceptions were analysed through qualitative content analysis (QCA) (Mayring, 2002), by developing categories in the following steps: (a) transcription of students` statements and editing to improve readability, (b) rearrangement of statements by content, (c) interpretation of the statements/drawings to find the underlying conceptions, and (d) revision and final formulation of the categories.

The team met each week to discuss and compare their findings and developed a collective interpretation of the data set by consensus (Stake, 1995; Corbin, 1990). To ensure the quality of the data analysis, all data were externally and consensually validated (Steinke, 2004) through discussion and verified with other studies in science education. The final interpretations of collated data resulted in three themes. One theme (i.e. isomerism in metal complexes) is discussed in the follow-up findings, supported by verbatim quotes that are representative of the voices from the students, using pseudonyms.

Out of ten generalized observations, two (2) quotations used in the study are representative statements from the 15 third year chemistry students of the University of Education, Winneba-Ghana. Extracted scientific diagrams on cis/trans metal complexes were diagnostic tool to generate students` conceptions on geometric isomerism. These diagrams were given to students to discuss, in order to assess their understanding about geometric isomerism. We have presented scientists' ideas on the concepts so that we can use it as basis to analyse the presentations from students and know where to start to build a bridge to blend the two ideas.

RESULTS

Scientific perspectives on geometric isomerism

According to scientists an octahedral metal complex of type **MA_4B_2** exhibiting a cis-trans formation could have the features portrayed in Figure 4 below. The study interprets **M** as the metal and **A, B** the ligands under consideration.

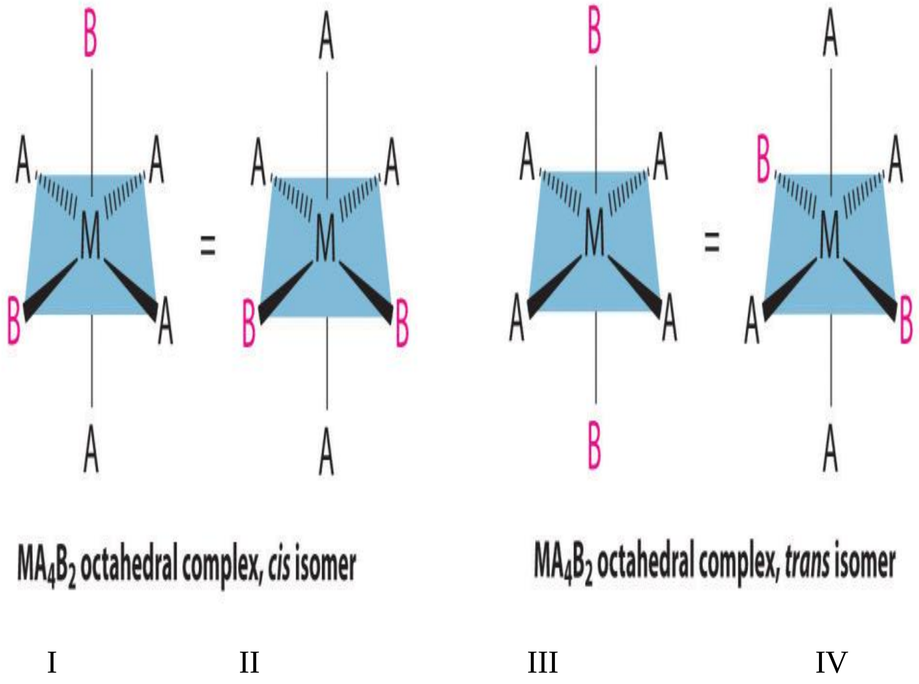

Figure 4: The scientists` perspective on geometric isomerism (chemwiki.ucdavis.edu)

From Figure 4, we see that the two ligands (**B`s**) in the octahedral complex are different from the other four ligands (**A`s**). Given a **MA_4B_2** type complex, two isomers are possible (i.e. I & II and/or III & IV). The two **B** ligands can be cis or trans, depending on their position in the coordination sphere. Considering ligand **B** on the same side of the sphere in I and II, the cis-isomer is possible. When the same ligand **B,** is located at the opposite side the trans-isomer occurs. Cis- and trans-$[Co(NH_3)_4Cl_2]^+$ are examples of this type of system in geometry.

Students` conceptions on geometric isomerism

When students were asked to discuss the cis-/trans isomers of the **MA_4B_2** complex as presented in Figure 4, they explained the orientations in Figure 4 by stating these comments:
` For the first two isomers presented, (Figures I & II), seriously, I will go in for trans-isomer, considering the square (equatorial), leaving the axial out, it looks like is **$MA_3B$** which always gives trans-isomer. For the Figure III, I will say is cis-isomer, the **A**`s in the

*square planer are the same plane (equatorial) and the **B**`s in the axial plane. ……. I will consider that as cis and not a trans-isomer. //... There is no way Figure II can be a cis-isomer; (...) it can never work`.*

(*Kwame, 28years)*

Another student also gave an account of her perception on the diagrams in Figure 4. She quoted the statement below.

*` I will consider Figures II and III as the same. On the square the **A**`s lie on the same plane likewise the **B**`s. And on the axial position the **A**`s lie in the same plane for Figure II and the same thing applies to Figure III. But when you look at Figure I, that happens to be an intervention of Figure II. So I would say Figure I is a trans-isomer of Figure II and Figure IV being a trans-isomer of Figure III. So II and III are cis-isomers whereas I and IV are trans-isomers`.*

(*Ekua 25years)*

In a second exercise, students were given a name of a complex to draw its geometry. The isomeric name of the compound was Cis-diammine-cis-diaqua-cis-dichloridochromium(III) ion. Examples of some diagrams drawn by the students are presented as Figures 5 and 6.

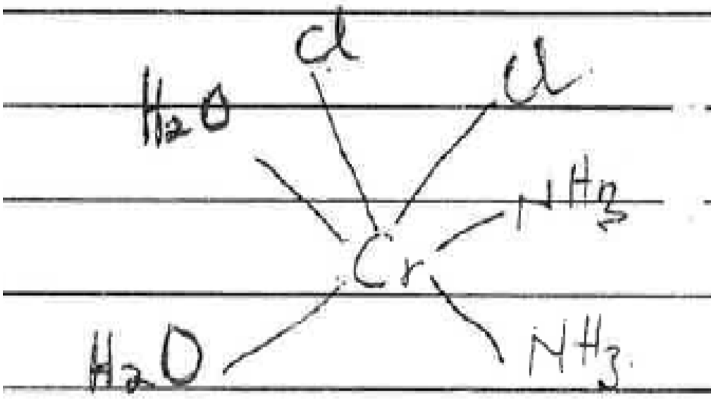

Figure 5: A representative diagram of a student`s drawing of Cis-diammine-cis- diaqua-cis-dichloridochromium(III) ion.

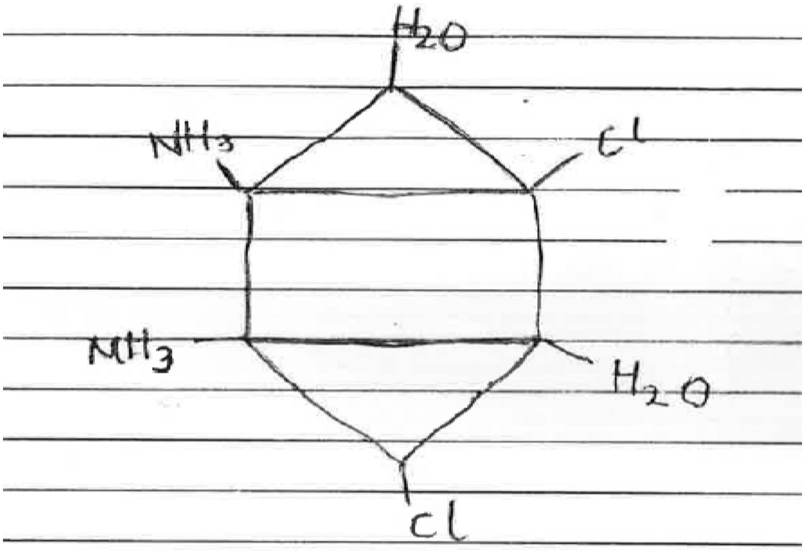

Figure 6: A student`s drawing of Cis-diammine-cis-diaqua-cis- dichloridochromium(III) ion.

After interpreting the students` drawings, their ideas were collated so that they could be used to develop new teaching guidelines. Students` collated ideas are summarised as follows:

i. Cis/trans effect were determined by metal-ligand bonds with `seeming` lines as represented in Figure 5.
ii. Exhibition of the cis-/trans orientation was about joining a square and triangles as portrayed in Figure 6.
iii. The central metal atom, **M**, was not considered in the drawing of the complex as in Figure 6

The students were expected to follow accepted scientists` perceptions in order to present the isomer shown as Figure 7 below.

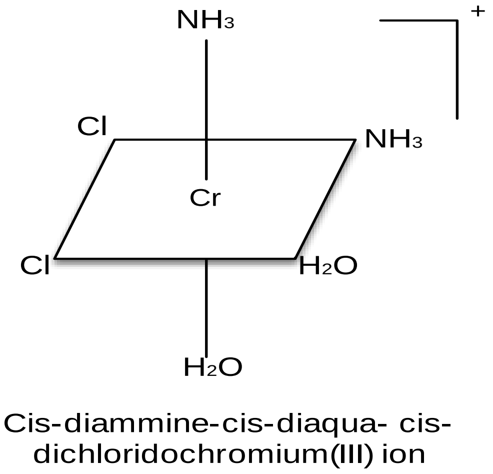

Figure 7: Scientists` diagram of Cis-diammine-cis-diaqua-cis- dichloridochromium(III) ion

Based on the Students' and Scientists` conceptions, these perspectives were brought together to design content-specific guidelines for teaching geometric isomerism.

DISCUSSIONS

Fusing Scientists` and Students` conceptions about geometric isomerism

Language is a window into students` conceptions. Hence if conceptions are expressed through various symbols of speech or drawings, then, students` statements could be regarded as representative of their conceptions, according to Niebert and Gropengiesser (2013). Speeches, such as the ones expressed by Kwame and Ekua, could be said to be representations of their conceptions on geometric isomerism.

From Kwame's group speech or explanation, they believe that an octahedral structure must be disintergrated in order to see its core structures. This, they imagined as a real separable square with two opposites lines. The square was therefore in the equitorial region supported by two lines (up and bottom) forming an octahedral. Kwame and the Scientists are in paritial accordance as pertains the drawing in Figure 4. Of course, the mid-section of the octahedral is a square with two (2) straight lines above and below the square. But, in sharp contrast to the Scientists` view, the square does not resemble an isomeric type **MA_3B**.

The isomeric type **MA_3B** stated by the student (Kwame), for example $[Pt(NH_3)_3(Cl)]^+$, interestingly cannot be of cis/trans effect. This is because of unequal distribution of ligands on one side/across the central metal atom, **M**. This study explains the **MA$_3$B** presentation with instances below in Figure 8.

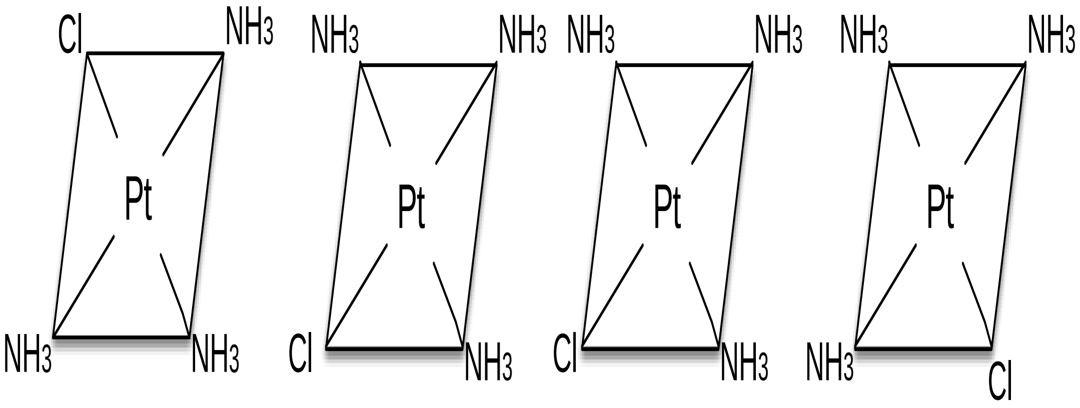

Figure 8: Diagrams of four(4) square-planar complexes shown, with no cis/trans- isomerism existence.

In a case where the three NH$_3$ are substituted with Cl, we may have the illustration portrayed in Figure 9.

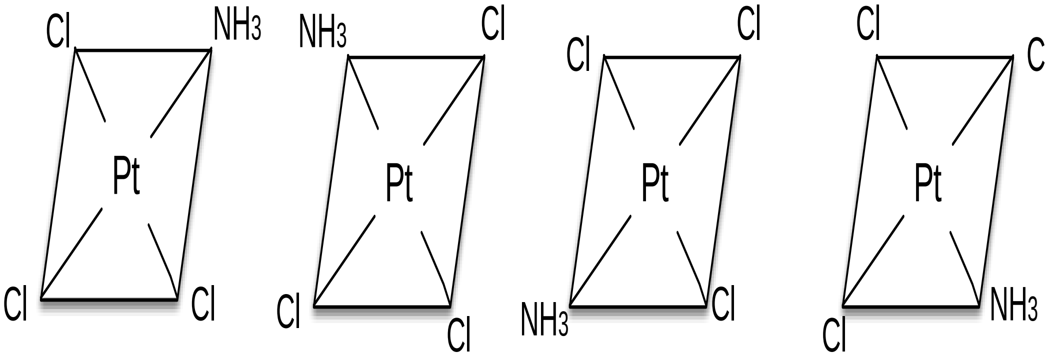

Figure 9: Representations of square-planar complexes without cis-trans isomers

Considering Figures 8 and 9, neither the cis- nor the trans isomer exist in any of the presentations. Kwame and his group members are not alone in this scientifically incorrect way of reasoning about geometric isomerism of octahedral complexes.

The group led by Ekua, had almost similar perceptions as Kwame`s group. That group also considered diagrams II and III in Figure 4 as being similar, both having cis-isomers, whereas through their interpretation assumed diagrams I and IV as trans-isomers. This is in sharp contrast to scientific view. Scientists` perceive diagrams I and II as cis-isomers while III and IV are considered as trans-isomers. The interpretation, in a much easier scientific sense, puts similar atoms/ions on or along the same side of the octahedron as cis-isomers. On the hand, if the same atoms/ions are on opposite sides, across the face of the octahedron, then the trans-isomer exists. The source of good judgement, whether a cis/trans complex octahedral may exist draws knowledge from the gestalts effects (Koffka, 1935) and embodied conceptions (Johnson, 1987). The Gestalt effect and embodied conception theories assert that, the entire whole of the complex is necessary and must not be considered in simple parts as the students` portrayed in this study.

Thus, scientific understanding, as abstract as it may be, is ultimately grounded in students` embodied conceptions (Johnson, 1987) through their first hand personal experiences or second hand (scientific) classroom experiences. It is not surprising that students represented the isomer in Figure 7 as `seeming` lines or just as combination(s) of simple triangles and squares of connecting bonds. The idea of lines and squares, is what learners are introduced to early in life. Thus, thinking chemically to make representations such as *cis-diammine-cis-diaqua-cis-dichloridochromium(III) ion* is often difficult for most chemistry students. In comparing the perception of experts (scientists) and novices (students) on a variety of chemical representations, Kozma and Russel (1997) reiterated that novices use only one form of representation and could rarely transform to other forms, whereas experts transformed easily. Novices relied on the surface features, such as lines, numbers and colour, to classify representations, whereas experts used an underlying and meaningful basis for their categorization. Olson, (1985) suggested that the act of drawings, however, go beyond recall of information (which is a low order thinking skill) and enhance the development of students' higher order skills. Once a drawing assignment is posed, it requires students to clarify meaning, justify their ideas, clarify inconsistent perspectives and summarize progress toward solving the problem. All these processes put together, provide higher-order level thinking. This implies that coordination chemistry content on isomerism has to be well connected in order to give the students a broader basis for conceptual change through compositions and diagrammatic expressions. The study puts forward simplified scientific content structure on geometric isomerism that contains enriched students` conceptions to make content structure accessible and comprehensensible.

The Model of Educational Reconstruction (MER), has obvious benefits for classroom practice in Higher Education (HE). Following the guiding pedagogical principles, a `restructured teaching/learning environments` philosophy could be used. A restructured teaching/learning environment begins with the assumption that knowledge is not directly transfered from scientists to students; that is, the constructivist approach is implemented and scientists-students content-oriented conceptual balances fromulated in an iterative process (Niebert & Gropengiesser, 2013). Students` need to recognise the classroom as a formal place to construct new knowledge and simply not make checks from scientific textbooks. Students` should practice a blend of their prior knowledge and the newly acquired scientific information through alternative explanations from companions (other groups) and discuss how to come out with sound science-oriented conceptions.

This compentency promotes open-ended science-oriented discussions which foster conceptual learning. A sound learning environment allows students to access their own conceptions, hoping for good trends and much better alternatives to explain and reflect on other students` view. Educational restructuring offers a form of platform or environment for reflection so that they would be able to examine misconcepts in the light of new authentic information. Thus, opportunities are given to students to revisit their own naive or alternate ideas, revise them, understand and relate concepts appropriately, and restore new scientific conceptions in a more intergrated trend . The period for reflection within the MER is seen as very important for concept restructuring and formation. Concepts on isomerism would be learned more efficiently if the restructured curriculum on coordination chemistry considers a fuse of both scientists` and students` conceptual corespondances in Ghanaian universities.

CONCLUSION

The study concludes that clarification of science content is mandatory for successful leaning environments. In this study, it was observed that there was a need to investigate students` prior conceptions and reconsideration within the learning discourse. We realised that scientists` and students` views on geometric isomerism have to be given equal consideration in the way each is presented, for a successful construction of the content structure for instruction. Thus, parallel analyses of both scientists` and students` conceptions about geometric isomerism were found to be mutually beneficial and important for redesigning teaching guidelines and learning environments to cater for students` learning demands.

We also found that, content structure in metal complex isomerism has to be simplified and enriched to engulf conceptual structures of students` conceptions. This would be a standpoint for designing a sustainable learning environment; a process of restructuring that would be studied in our next paper.

ACKNOWLEDGEMENTS

Most of the background support for this article came from the DAAD, Government of Ghana (MoE) and the North-South Coorperation (UZH).

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